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Method and forming machine for manufacturing a product having various diameters

The invention relates to a method and a forming machine suitable for manufacturing a product having various diameters from a workpiece, such as a metal cylinder or plate, in which the workpiece is clamped down in a clamping device, the workpiece and a first tool are rotated about an axis of rotation relative to each other, the workpiece is deformed by means of said first tool by placing the tool into contact with the workpiece and moving the workpiece and/or the tool in a direction along, i.e. parallel to or having a component parallel to, the axis of rotation.

Such a method and apparatus are known, e.g. from EP 0 916 426. Said publication describes how one end of a cylindrical workpiece is worked by clamping down said workpiece in a clamping device (indicated by numeral 12 in Fig. 1 of EP 0 916 426) and deforming said ends by means of three forming rollers (28), which are mounted on a rotary member (24). Said forming rollers (28) rotate in the same plane and are pressed against the workpiece at three locations which are evenly distributed over the circumference of the workpiece, after which said rollers move along a number of paths along the workpiece so as to deform the workpiece in steps.

For the sake of completeness, attention is drawn to DE 23 27 664 en DE 1964 401, in which methods and apparatuses are described for flow pressing cylindrical tubes, i.e. tubes having a constant diameter. The methods and apparatuses according to these documents are unsuitable for manufacturing a product having various diameters.

The object of the invention is to provide an improved method and forming machine.

In order to accomplish that objective, the method and the forming machine referred to in the first paragraph are characterized in that at least a second tool is placed into contact with the workpiece at a position behind the

first tool, seen in the working direction, and in that the workpiece is also deformed by means of said second tool. Preferably, at least a third tool is placed into contact with the workpiece behind said second tool.

Thus, parts of the workpiece that have been deformed by the first tool are deformed by one or more subsequent tools almost immediately. As a result, the material, such as aluminium or steel, will have a relatively very limited opportunity, if any, to harden, so that the next operation will proceed relatively easily and the risk of the material being damaged or adversely affected is considerably reduced.

Preferably, the tools each comprise two or more forming rollers, between which the workpiece is retained while being worked and which occupy substantially the same axial position with respect to the workpiece. It is possible to impose relatively large as well as relatively small diameter changes by means of forming rollers. Such rollers are preferably freely rotatable about an axis which extends either horizontally or at an angle with respect to the aforesaid axis of rotation. Furthermore, it is preferred that most or all of the tools form part of one and the same deforming head, or that they are at any rate positioned relatively close together. The question as to the most suitable spacing between successive tools, at least between the positions at which the tools make contact with the workpiece, depends on the properties of the workpiece, of course, and on the nature of the working process to be carried out. In many cases said spacing will vary between 1 and 30 cm.

If the material and the dimensions of the workpiece and the intended product (frequently a semifinished product) allow so, the number of working cycles can be reduced to one, if desired. A surface that has been worked once will not be worked anew in that case, so that the load to which the material is subjected will remain limited. In addition to that the programming of any control equipment that may be provided will be significantly simpler, in particular because it will not be necessary to take the shape and the behaviour of various intermediate forms into account.

For the sake of completeness it is noted that British patent application No. 238,960 describes a roller by means of which the diameter of bars, pipes and the like is reduced to a smaller, uniform diameter in a continuous process, using a number of tools arranged in succession.

Further, attention is drawn to US 5,428,980, in which a workpiece is deformed with a first forming roller and glazed with a second roller. A second forming roller is not described.

The invention will be explained hereinafter with reference to the figures, which show a number of embodiments of the method and the forming machine according to the present invention.

Figs. 1A and 1B schematically show the deformation of one end of a cylindrical workpiece by means of five tools.

Figs. 2A and 2B show the eccentric deformation of one end of a workpiece by means of three tools.

Figs. 3A - 3C show the fixing of an insert member in a cylindrical workpiece, using a method comparable to the method as used in Figs. 2A and 2B.

Fig. 4 is a cross-sectional view of a forming machine for eccentric deformation of a workpiece, which machine comprises four tools.

Figs. 5A and 5B are front views of a workpiece which has been subjected to one operation and two operations, respectively, by means of the forming machine of Fig. 4.

Fig. 6 is a top plan view of a forming machine which is in particular suitable for deforming relatively long workpieces.

Figs. 7 and 8 are a front view and a perspective view, respectively, of a so-called carriage for use in a forming machine as shown in Fig. 6.

Figs. 9A and 9B are schematic sectional views of the carriage of Figs. 6 - 8.

Fig. 10 shows the flow forming process carried out by using the present invention.

Fig. 11 shows the so-called bottom-closing process carried out by using the present invention.

Figs. 12A - 12D schematically show the rotary deep drawing of a plate-shaped body carried out by means of seven tools.

Figs. 13A - 13D schematically show the projection of a plate-shaped body by means of six tools.

Figs. 14A - 14D schematically show a variant of the projection process as carried out in Figs. 13A - 13D.

Parts which are identical or which have the same or substantially the same function will be indicated by the same numerals as much as possible hereinafter.

Figs. 1A and 1B schematically show a method and apparatus according to the present invention. A workpiece 1, in this case a metal cylinder, is rotated about an axis of rotation 2 at a certain number of revolutions. Subsequently a deforming head (not shown) is provided, in which five tools 3A - 3E are rotatably mounted. Each tool 3 comprises two forming rollers arranged in mirror symmetry with respect to the axis 2. The radial distance from the tools 3 to the axis 2 decreases stepwise towards the rear, seen in the working direction 4.

Fig. 1A shows the start of the operation, in which the first forming rollers 3A just make contact with the edge of an end of the rotating workpiece 1, whilst Fig. 1B shows the situation after one working cycle, in which the forming rollers 3 have made a full pass in the working direction 4, having deformed the workpiece 1 into a product having five gradually decreasing (in steps) diameters. The part having the smallest diameter has been deformed on a mandrel 5 by the final forming rollers 3A, so that the inside diameter of said part is precisely calibrated.

The magnitude of the steps by which each tool 3 is positioned closer to the axis of rotation 2 than the preceding tool inter alia depends on the design, the material and the dimensions of the unformed workpiece, of course. In the case of a workpiece having a small wall thickness, it will usually be possible to use larger steps.

Figs. 2A and 2B show a second embodiment of the present invention, in which the tools 3A - 3C, likewise compris-

ing two forming rollers each in this embodiment, are freely rotatable in holders 6A - 6C. The holders 6 are in turn rotatably mounted, about an axis of rotation 2, in a deforming head 7 (schematically shown). Also in this embodiment the radial distance from the tools 3 to the axis 2 decreases in steps towards the rear. The holders 6 can be adjusted independently of each other in radial direction. This makes it possible to position said holders 6, and thus the axis of rotation 2 of each of the tools 3, eccentrically with respect to the central axis 8 of the (undeformed as yet) workpiece 1.

By rotating the holders 6 and moving the deforming head 7 in the working direction 4, using driving means 9 (schematically shown) such as a pneumatic or hydraulic cylinder or an electric motor fitted with a spindle, over a workpiece 1 clamped down in a fixed clamping head 10 (schematically shown), said workpiece 1 is deformed in one single operation, in which the worked parts obtained are positioned eccentrically with respect to the axis 2.

For the sake of completeness it is noted that the frictional heat which is generated during the deforming operation can be influenced by disposing the forming rollers at an angle with respect to the axis of rotation 2. In the case of an inclined position (Fig. 2A) less frictional heat will be generated than in the case of a position at right angles (Fig. 2B). This position may be varied in dependence on the heat that is required with a particular operation.

Figs. 3A - 3C show how parts can be fixed in a workpiece by means of the forming machine as shown in Fig. 2B, e.g. in order for the purpose of manufacturing a catalytic converter for a passenger car.

First a so-called *catalytic brick* or *substrate* 11A and an insert member 11B are placed in the workpiece 1 (Figs. 3A and 3B). The insert member 11B may be supported and placed by means of, for example, an axially adjustable mandrel (not shown) mounted in or through the deforming head 7. Following that, the workpiece 1 is deformed by a deforming head 7, in which the end of the workpiece 1 is pressed onto the end of

the insert member 11B and in which a substantially gastight connection between the two ends is obtained.

Fig. 4 is a cross-sectional view of a second forming machine for eccentric deformation of a workpiece, which machine comprises four tools 3A - 3D. Each tool 3 comprises minimally one forming roller, which is (are) mounted freely rotatable on a separate holder 6A - 6D. The holders 6 are arranged in pairs, opposite each other, in four separate rotationally symmetrical housings 12A - 12D, which housings in turn form part of a deforming head 7. The first housing 12A comprises a substantially annular, static outer part 13A, in which a, likewise substantially annular, inner part 14A is rotatably mounted in bearings 15A. The inner part 14A may e.g. be driven by means of a motor 16A (schematically shown), whose drive shaft is fitted with a pinion 17A, which engages in a set of teeth present on the circumference of the inner part 14A. In addition, an annular element 18A of wedge-shaped section, which element 18A mates with an end 19A, likewise of wedge-shaped section, of the respective holder 6A, is present in said inner part 14A. By moving the annular element 18A to the left or the right (in the drawing), using driving means 20A, the holders 6A, and thus the forming rollers mounted thereon, are moved radially inwardly or outwardly, respectively. Furthermore, driving means 21A are provided, by means of which the housing 12A can be adjusted in axial direction, parallel to the axis of rotation 2, with respect to the other housings 12.

The other three housings 12B - 12D correspond to a large extent to the first housing 12A, but in addition they comprise a circular cylindrical part 22, whose outside diameter is smaller than the inside diameter of the housing 12 to the left (in the drawing) thereof. As a result, the housings 12 can also be adjusted in radial direction relative to each other, independently of each other, by means of respective driving mechanisms 23A - 23D, and the axis of rotation 2 of each of the housings 12 can be positioned eccentrically relative to the central axis of (the part as yet undeformed of) a workpiece.

The annular elements 18B - 18D in turn each comprise a cylindrical part 24, whose outside diameter is smaller than the inside diameter of the inner part 14B - 14D. Furthermore, the deforming head 7 comprises driving means 9, by means of which said head 7 can be moved forward and backward in the working direction. Examples of the aforesaid driving means 9, 20, 21 and 23 include a pneumatic or hydraulic cylinder or an electric motor fitted with a spindle. The driving means are not limited to the above examples, of course.

Figs. 5A and 5B are front views of a workpiece 1 which has been deformed into an (intermediate) product 25 comprising four reduced portions in one working cycle. By subsequently adjusting the tools 3 in outward direction, the (intermediate) product 3 can be deformed into a product 25 comprising a total of eight reduced portions in a working cycle, in which the stroke is extended by half the axial distance between the first reduced portions. It stands to reason that it is possible to adapt inter alia the number of tools 3, the number of working cycles and the degree to which the tools are adjusted to the required product. Thus Fig. 4 shows a working process in which the tools are adjusted during the working cycle(s), so that a product having a continuously decreasing diameter, in this case a product having a conical end, is obtained.

Fig. 6 is a top plan view of a forming machine by means of which also relatively long cylindrical workpieces 1 can be deformed. The forming machine comprises a frame 30, which is provided with guide rails 31, 32 on either side, on which a transversely arranged subframe 33 is supported, over which guide rails three so-called carriages can be moved.

The subframe 33 comprises a clamping head 34, in which a first end of a workpiece 1 can be clamped down and which can be rotated, e.g. by a motor which is accommodated in a housing 35.

The first carriage 36 is provided with a carrier plate 37, on which four tools 3 are mounted. Each tool comprises two forming rollers, which are mounted freely rotatable in holders 38 positioned directly opposite each

other. Said holders 38 are in turn tiltably mounted, about respective tilting points 39, on radially adjustable supports or slides 40 and they can be tilted in a direction towards the axis of rotation 2 and in a direction away therefrom, using driving means such as electric motors 41 or hydraulic cylinders, which are likewise mounted on respective slides 40. The slides 40, and thus the holders 38 and the forming rollers, can be adjusted in radial direction, using driving means 9. In the illustrated embodiment, the slides 40 are moreover detachably connected to the carrier plate 37, so that the number of slides 40, the number of tools 3 and the positions thereof can easily be adapted to the product to be manufactured. In the illustrated embodiment, the tilting points 39 are located behind the tools 3, seen in the working direction, but said tilting points 39 may also be located at other positions, e.g. in front of or between the tools 3, depending on the operation, or they may even be adjustable. In the latter case the tilting points can be shifted during operation.

The second carriage 42 comprises a passage 43, in which a centring unit, e.g. a bush (not shown), is present, whose central axis coincides with the axis of rotation 2 and which functions to centre a workpiece present therein with respect to said axis 2. The third carriage 44 comprises a so-called tailstock 45, which supports the other end of the workpiece 1 during the operation and which comprises a mandrel 5 or clamping mandrel. Depending on the operation, the second and/or the third carriage can be coupled to the first carriage, e.g. if it is desirable to maintain a substantially constant distance between the first and the second carriage.

A cylindrical workpiece 1 can be loaded into the forming machine, e.g. by moving the third carriage 44 to the front (to the left in the figure) and moving the first and second carriages 36, 42 to the rear until the distance between the third carriage 44 and the second carriage 42 is greater than the length of the workpiece 1. Then the workpiece 1 is guided through the passage 43 and between the tools 3 with its first end and clamped down in the clamping

head 34. The mandrel 5 is placed in the second end of the workpiece 1, after which the workpiece 1 is centred, the tools 3 are set and the mandrel 5 is placed into contact with the wall of the workpiece 1. It is also possible to remove the worked workpiece 1 automatically, e.g. by means of a *pick and place* system, after an operation, when all three carriages are positioned on the left, and load a next workpiece into the machine in the same position of the carriages.

The outside diameter of the workpiece 1 can be reduced to a smaller, constant outside diameter, e.g. along the full length of the workpiece, by rotating the workpiece 1 about the axis of rotation 2, gradually tilting the tools 3 and moving the slides 40 in radial direction towards the workpiece 1 and initiating a translating movement of the carriages. The rear tool 3D will be the first to make contact with the workpiece 1, followed by the third, the second and the first tool, respectively. It is also possible to have 3D and 3C, or even all the tools 3, make contact with the workpiece at the same time. The so-called "escaping" of the material can be suppressed more easily in this way.

Preferably, the end of the mandrel 5 is only spaced from the front tool 3 by a small distance at all times, at any rate towards the end of a working operation, in order to support the workpiece 1 up to a point just before the working zone and thus further enhance the degree of stability. In addition, the mandrel 5 can be used for generating a tensile force in the workpiece 1. Such a tensile force can be used for adjusting the reduction of the wall thickness along the entire length, or practically the entire length, of the product or in particular zones thereof. As the force exerted on the workpiece by means of the mandrel 5 increases, the rate at which the material of the workpiece 1 is pulled from the mandrel 5 will decrease, which will in turn result in a smaller wall thickness. It is noted that the tensile force in the workpiece can be varied by means of the aforesaid centring unit in the passage 43 as well. Thus the tensile force can be imposed at the start of the working process, for example, in particular by means of said centring unit, whilst the

tensile force can be imposed mainly by the mandrel 5 towards the end, when the workpiece 1 starts to exit from the bush.

Incidentally, wall thickness and wall thickness variations can be controlled by varying the radial distance between consecutive tools, for instance by tilting the holders and translating the holders in radial direction, preferably simultaneously. By increasing or decreasing the radial distance between the tools, the wall thickness at that location will be reduced or increased respectively.

Figs. 7 and 8 show variants of the first carriage 36, in which the carriage is shown to be fitted with, respectively, two and six tools.

Figs. 9A and 9B show the manner in which the tools 3 can be tilted towards the workpiece in carriages as shown in Figs. 7 and 8 and, after the tools have started their working stroke, be moved in radial direction towards the definitive working position. Using the apparatus as shown in Figs. 6 - 9B, a tapered and/or stepped product can be obtained, for example, by adjusting the tools 3 during operation. It is also possible to form two or more products from a workpiece and subsequently separate said products from each other.

The number of revolutions, the magnitude of the steps and the rate of translation of the tools depend on factors such as the material being used, the outside diameter and the wall thickness of the workpiece and the dimensions of the intended product. An aluminium tube having a diameter of 25 cm and a length of 4 m, for example, can e.g. be formed into a conical tube having a diameter which decreases from 16 cm to 8 cm and a length of 7 m. Such an operation can usually be carried out at a rotational speed of 200 - 700 revolutions per minute.

Fig. 10 shows an embodiment in which a cylindrical workpiece 1 is placed onto a mandrel 5 until the closed bottom of said workpiece 1 abuts against the end of the mandrel 5, which workpiece is clamped down by means of a tailstock (not shown) and deformed by means of a flow turning operation. This makes it possible to control the surface quality of the inner wall and, more in particular, prevent porosity

of said inner wall. In addition to that it is possible to manufacture a finished product having a variable wall thickness in a single working cycle by adjusting the tools in radial direction during operation.

Fig. 11 shows how the invention can be used for a process that is also referred to as "bottom closing". In this process, the open end of a cylindrical workpiece 1 is closed in one operation, using a number of tools 3 which are each mounted on their own slide, and which can thus be moved relative to each other. Said adjustable slides are in turn mounted on a support (not shown), which can be pivoted about an adjustable pivot point 39, using driving means as already mentioned before. Since the respective operations of the tools are carried out in quick succession, the risk of adverse effects caused by premature cooling is considerably reduced or even practically eliminated.

Figs. 12A - 12D show an example of the rotary deep-drawing of a plate-shaped workpiece 1, in this case a metal disc, in which said workpiece 1 is pressed against the central part of a bobbin 46 by means of a tailstock (not shown) and is rotated together with the aforesaid parts. The workpiece is deformed by means of five tools 3, which each comprise a number of forming rollers. Said forming rollers are each mounted on a separate slide (not shown), so that the rollers can be moved relative to each other during the deforming process. The edge of the workpiece 1 is stabilised by a support or holding-down clamp 47, at least during the initial part of the operation. In the illustrated example, the final tool 3E can directly move along a path corresponding to the outside diameter of the intended product, because the other tools 3A - 3D have sufficiently pre-formed the workpiece 1.

Fig. 13A - 14D show examples of the so-called projecting of a plate-shaped workpiece 1, likewise a metal disc in this case, which is pressed against a bobbin 46, by means of a tailstock (not shown), and rotated. The workpiece is deformed by means of seven tools 3, viz. six discs 3A - 3F and one forming roller 3G, which are mounted on a common tiltable

slide. The discs mainly function to pre-form the edge of the workpiece relative to the block 46, whilst the forming roller projects the material by means of a flow turning operation. Figs. 14A - 14D show how the forming roller on the one hand and the six discs on the other hand are mounted on either side of the block 46, each on a separate holder 47, 48, which holders can be moved in the X-direction and the Y-direction by means of two respective slides. For more details with regard to the projection process, reference is made to EP 0 774 308.

If the workpieces are deformed in only one working cycle in the forming machines as described above, the tools, the centring means and the like will require no readjustment, and in many cases less residual material, e.g. an undeformed end which was fixed in a loose chuck, or even no residual material at all will remain.

The forming machines according to the present invention can be operated by a person as well as by a control unit, of course. Such a control unit will be arranged, for example, for controlling the movement of the tools and the workpiece relative to each other, e.g. in axial and radial direction or along X- and Y-coordinates, in accordance with a control programme stored in a memory, in such a manner that the tools will move along one or more desired paths for forming the workpiece into the desired finished product or intermediate product.

Although the invention has been explained on the basis of a circular cylindrical metal workpiece in the foregoing, the invention can also be used with workpieces of unround section(s), such as oval, substantially triangular or multilobal sections. The invention can furthermore be used for hot forming as well as for cold forming.

The term "tool" as used within the framework of the present invention inter alia comprises a single forming roller and sets of two or more such forming rollers, which take up substantially the same axial position with respect to the workpiece.

Consequently, the invention is not restricted to the embodiments as described above, which can be varied in many ways within the scope of the invention as defined in the claims.